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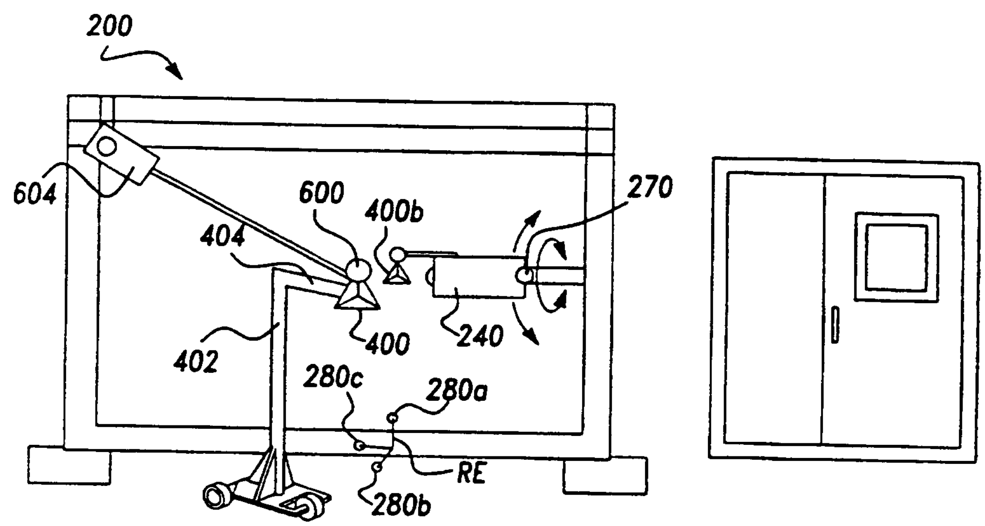
(54) Title: METHOD AND APPARATUS FOR CALIBRATING A NON-CONTACT GAUGING SENSOR WITH RESPECT TO AN EXTERNAL COORDINATE SYSTEM



(57) Abstract

The laser tracker (604) is positioned at a vantage point to detect and calibrate its reference frame to the external reference frame demarcated by a light-reflecting retro reflector (600). A tetrahedron framework (400) with retro reflector (600) mounted on one of the vertices serves as a reference target that is placed in front of the feature sensor (240) to be calibrated. The laser tracker (604) reads and calibrates the position of the retro reflector and thus the tetrahedron while the structured light of the feature sensor (240) is projected onto the framework of the reference target. The structured light intersects with and reflects from the reference target, providing the feature sensor (240) with positional and orientation data. These data are correlated to map the coordinate system of the feature sensor to the coordinate system of the external reference frame.

METHOD AND APPARATUS FOR CALIBRATING A NON-CONTACT GAUGING SENSOR WITH RESPECT TO AN EXTERNAL COORDINATE SYSTEM

Cross-Reference To Related Application

This is a continuation-in-part of U.S. Patent Application Serial Number 08/597,281, filed February 6, 1996, entitled "Method And Apparatus For Calibrating A Non-Contact Gauging Sensor With Respect To An External Coordinate System", assigned to the assignee of the present invention.

Background and Summary of the Invention

The present invention relates generally to non-contact gauging systems. More particularly, the invention relates to an apparatus system and method for calibrating non-contact gauging systems.

Demand for higher quality has pressed manufacturers of mass produced articles, such as automotive vehicles, to employ automated manufacturing techniques that were unheard of when assembly line manufacturing was first conceived. Today, robotic equipment is used to assemble, weld, finish, gauge and test manufactured articles with a much higher degree of quality and precision than has been heretofore possible. Computer-aided manufacturing techniques allow designers to graphically conceptualize and design a new product on a computer workstation and the automated manufacturing process ensures that the design is faithfully carried out precisely according to specification. Machine vision is a key part of today's manufacturing environment. Machine vision systems are used with robotics and computer-aided design systems to ensure high quality is achieved at the lowest practical cost. Achieving high quality manufactured parts requires highly accurate, tightly calibrated machine vision sensors. Not only must a sensor have a suitable resolution to discern a manufactured feature of interest, the sensor must be accurately calibrated to a known frame of reference so that the feature of interest may be related to other features on the workpiece. Without accurate calibration, even the most sensitive, high resolution sensor will fail to produce high quality results.

relative to the external reference frame. It is a trial and error process. If the sensor needs to be reoriented (as is often the case), the theodolites must be manually retrained on the target after each sensor position adjustment. For more information on this calibration technique, see U.S. Patent No. 4,841,460 to Dewar et al.

Whereas both of the aforementioned calibration techniques do work, there is considerable interest in a calibration technique that is quicker and easier to accomplish and that eliminates the need to rely on expensive master parts or difficult to use theodolite equipment. To this end, the present invention provides a calibration system that can be used in a matter of minutes, instead of hours, and without the need for precisely manufactured master parts or theodolite equipment. One of the major advantages of the invention is that it allows the calibration of a sensors to be checked or realigned between line shifts, without requiring the line to be shut down for an extended period.

The system employs a portable reference target that has a retroreflector mounted at a known location with respect to the center of the tetrahedron. The retroreflector is designed to reflect light from a companion laser tracker that is servo controlled to track the position of the retroreflector with its laser beam. The laser tracker is thereby able to acquire the position of the retroreflector (and thereby acquire the position of the attached portable reference target.)

The presently preferred portable reference target is a tetrahedron framework that provides at least three noncolinear and noncoplanar geometric structures (e.g., straight edges) that are illuminated by structured light emanating from the feature sensor. These noncolinear geometric features provide the feature sensor with unambiguous spatial data for measuring the spatial position and attitude of the target.

The system further includes a coordinate translation system for coordinating the readings from the laser tracker and from the feature sensor. More specifically, the translation system is adapted for coupling to the laser tracker to the feature sensor to collect data read by these sensors. The translation system establishes a first relationship between the reference frame of the laser tracker and the external reference frame with which the reference indicia are associated. The translation system also collects data from the portable reference target as viewed by both laser tracker and feature sensor and establishes a second relationship between the laser tracker reference frame and the feature sensor reference frame. Finally, the

Figure 4 is perspective view of an alternate embodiment of the invention employing laser tracker and retroreflector;

Figure 5 is a detailed view of the retroreflector, showing the reflective surfaces; and

Figure 6 is a home nest calibration apparatus used to zero the retro reflector.

Description of the Preferred Embodiment

With reference to Figure 1, there is shown a typical automotive vehicle body portion which, prior to its assembly with other of the vehicle components, would require gauging of certain key points. Such miscellaneous points of interest on workpiece **100** of Figure 1 are shown as points **110-1** through **110-n**. The left side **100L** of the vehicle body and the right side **100R** of the vehicle body are shown in an "unfolded" view for convenience in Figure 1. Typical usages of the points or the manner in which they are selected would be dictated, for example, by the ensuing assembly process to take place with respect to the workpiece **100**. For example, assume that the hood has not yet been assembled over the hood cavity at the front of the vehicle. Then measurements about the periphery of the hood cavity, such as at points **110-6**, **110-7**, **110-8**, and **110-9** could be made to determine whether the ensuing assembly of the hood lid to the vehicle body can be performed with an acceptable fit between the parts to be assembled.

While there are many sensor arrangements known, including the optical arrangement disclosed in U.S. Patent 4,645,348 to Dewar et al., assigned to the assignee of the present invention, it has been time consuming to calibrate the sensor readings at all the desired points of interest about a large workpiece with respect to any desired external reference frame. The present invention addresses the need for faster calibration.

A typical gauging station for an automotive vehicle part as shown in Figure 1 could take the form shown in Figure 2. Workpieces to be gauged at gauging station **200** rest on transporting pallets **220**, which are moved along an assembly line via pallet guides **230** that pass through guide channels **231** in the pallet. At the gauging station **200**, a sensor mounting frame **210** (only one half of which is shown in perspective in Figure 2) surrounds the workpiece **100** to be gauged and provides a plurality of mounting positions for a series of optical gauging sensors or feature

structure **602** that has the reflective property of reflecting an incoming light ray back to its source. The cornered mirror is formed by three intersecting mirrored planes that meet at right angles, like the corner formed by the intersecting walls and ceiling of a rectangular room. The retroreflector exhibits the retro-reflective property over a usable range of approximately 40-60°. Thus it will return an incoming beam of laser light originating from a position essentially anywhere within a 40-60° semisphere centered on a line that bisects the retro reflective corner. The illustrated reflector is a corner reflector that has a ±40° range. A "cat's eye" reflector will give a ±60 range.

Referring to Figure 4, the system includes a servo driven laser tracker **604** that emits an outgoing laser beam **606** and detects an incoming laser beam **608**. The laser tracker includes a servo drive mechanism **610** with closed loop controller **612** that points the laser tracker in the direction of the incoming beam **608**. As long as the laser tracker is within the 45-60° field of view of the retroreflector, the laser tracker will precisely follow or track the position of the retroreflector.

The interferometer within the laser tracker allows the system to achieve very high accuracy. The current embodiment will track the position of the retroreflector within 50 microns. Thus the retroreflector and the laser tracker system can precisely track where the center of the retroreflector is at all times, even as the retroreflector is moved around.

The retroreflector is preferably mounted on a vertex of the tetrahedron framework, and the framework is provided with a mounting fixture **614** for attachment to the robot gripper, or to some other suitable structure, such as a tripod stand **402** (Figure 3). By securing the retroreflector to the tetrahedron and by then calibrating the reflector relative to the fixture **614**, the center of the retroreflector (the corner point at which the mirrored surfaces mutually intersect) may be geometrically calibrated in terms of an offset relative to the location and orientation of the mounting fixture **614**. This calibration may be done by moving the assembly to three or four different locations within a previously calibrated structured light sensor measuring zone, while monitoring the output **620** of controller **612**. Ideally, this calibration should be done using a sufficient number of measurements to ensure that the X, Y, Z offset between the center of the retroreflector and the mounting fixture **614** is known. This offset is shown by dotted lines **622** in Figure 4.

In use, the laser tracker embodiment can be used to link the external

What Is Claimed Is:

1. A sensor calibration system for calibrating a feature sensor with respect to an external reference frame, the feature sensor of the type having a sensing zone associated with a sensor reference frame comprising:

retroreflector disposed in fixed relation to said external reference frame;

a laser tracker having a calibration field of observation associated with laser tracker reference frame, said laser tracker being positionable at vantage point such that said retroreflector is within the calibration field;

a reference target for placement within the observation field of said laser tracker and within the sensing zone of said feature sensor;

a coordinate translation system being adapted for coupling to said laser tracker for collecting data from said retroreflector and for establishing a first relationship between the laser tracker reference frame and the external reference frame;

said coordinate translation system further being adapted for coupling to said laser tracker and to said feature sensor for collecting data from the reference target and for establishing a second relationship between the laser tracker reference frame and the feature reference frame; and

said coordinate translation system determining a third relationship between the external reference frame and the feature reference frame, whereby the feature sensor is calibrated with respect to the external reference frame.

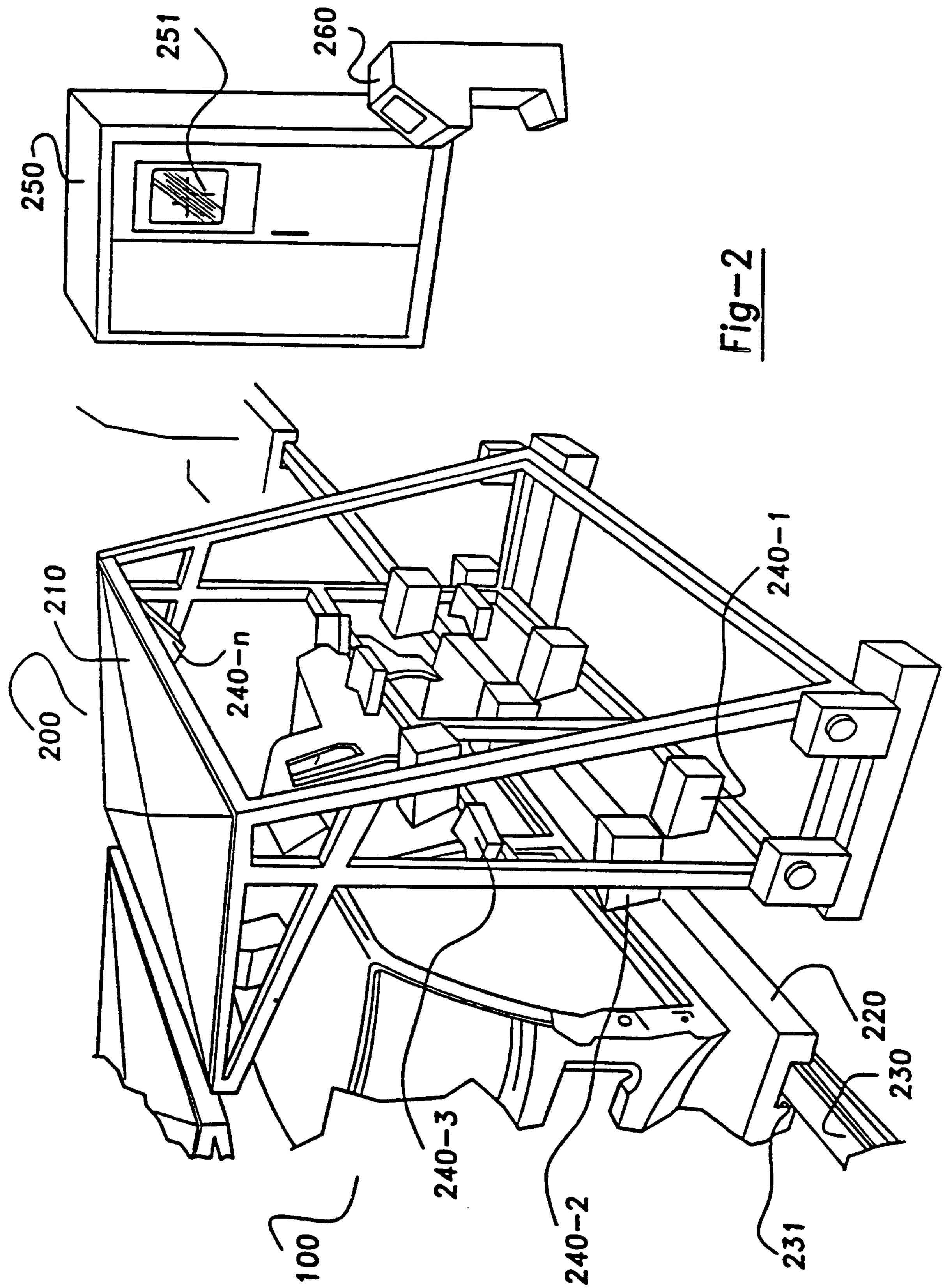


Fig-2

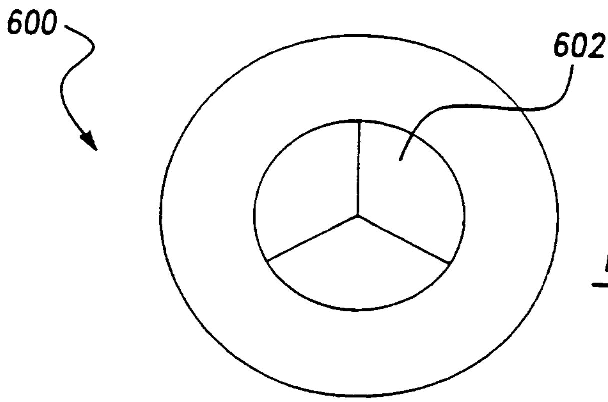


Fig-5

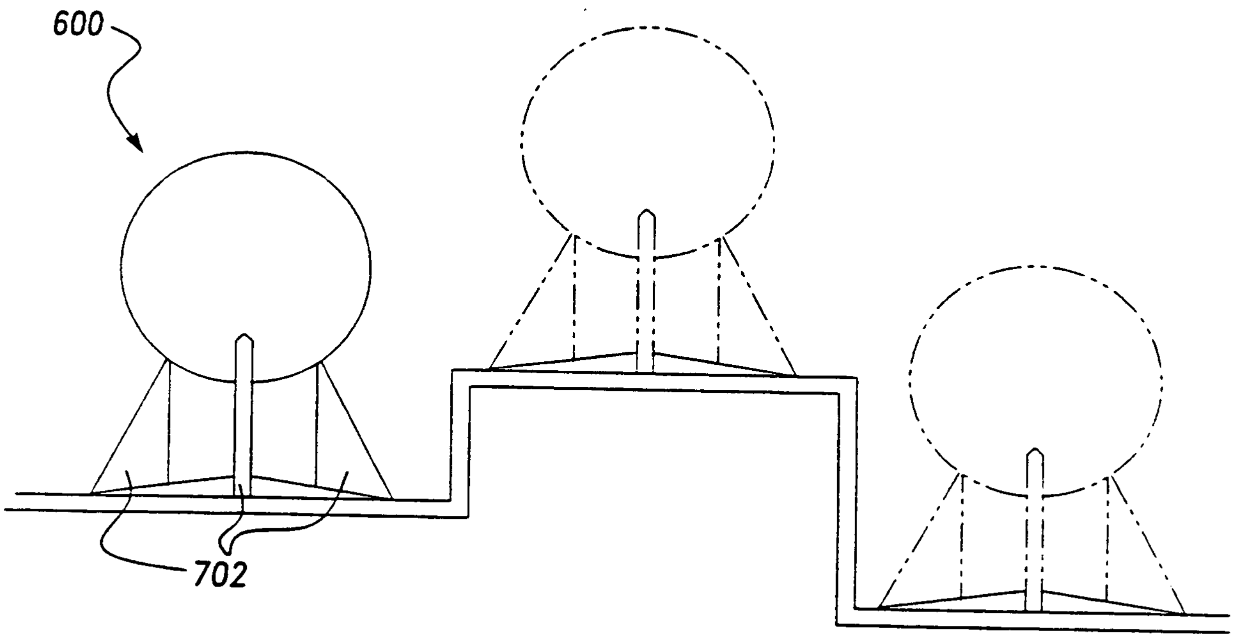
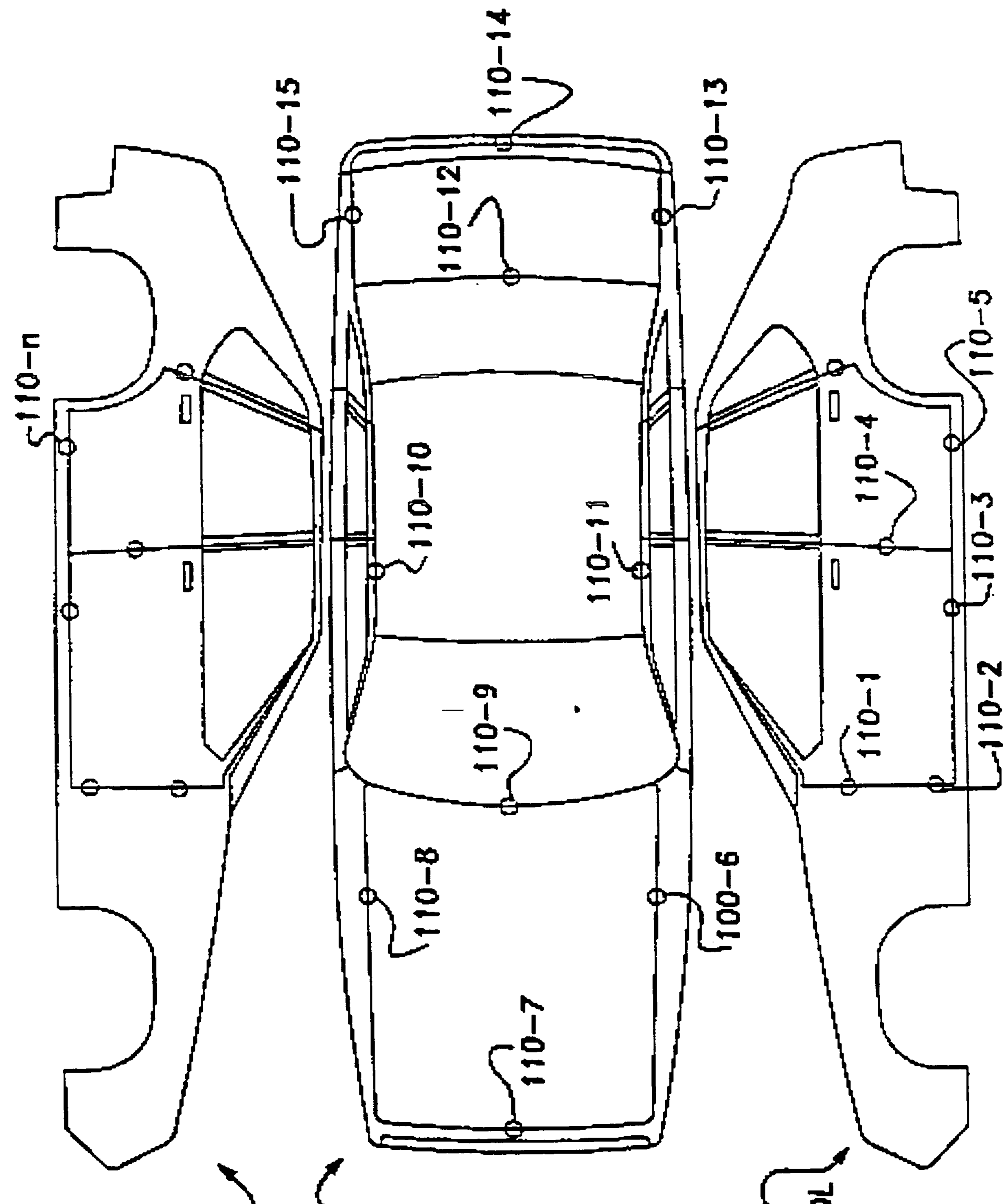


Fig-6

B. FIELDS SEARCHED
Minimum documentation searched
Classification System: U.S.

702/94, 95, 104, 152, 153, 36, 40, 93, 97, 105, 113, 116, 150, 151, 158, 159, FOR 163, FOR 159, FOR 160, FOR 156, FOR 157, FOR 145, FOR 146, FOR 147, FOR 148; 356/375, 139.03, 152.2, 152.3, 139.04, 376, 383, 141.1, 3.01, 3.02, 3.03, 3.04, 3.06, 3.07, 3.08, 3.09, 3.1, 3.11; 364/167.04, 167.05, 167.06, 167.08, 167.1, 167.12, 528.37, 528.38; 382/103, 106, 151, 312, 313, 317, 321; 33/545, 546, 547, 288, 502, 503, 504, 505, 506, 791; 73/1.75, 1.79; 901/9, 44, 45, 46, 47; 250/231.11, 208.1, 203.1, 203.2, 203.3, 227.2, 559.1, 559.2, 559.29, 559.33, 339.09


110-14
110-15
110-13
110-12
110-n
110-5
110-4
110-10
110-11
110-3
110-9
110-1
110-2
110-8
100-6
110-7
100R
100
100L

Fig—1

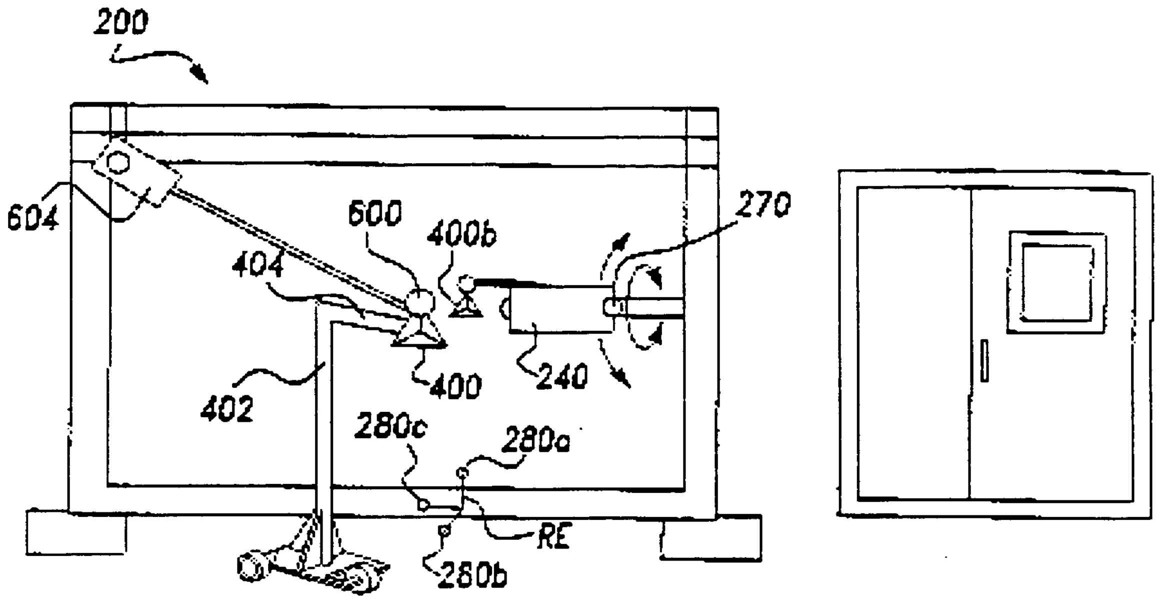

200
604
600
400b
270
404
402
400
240
280c
280a
RE
280b

Fig-3

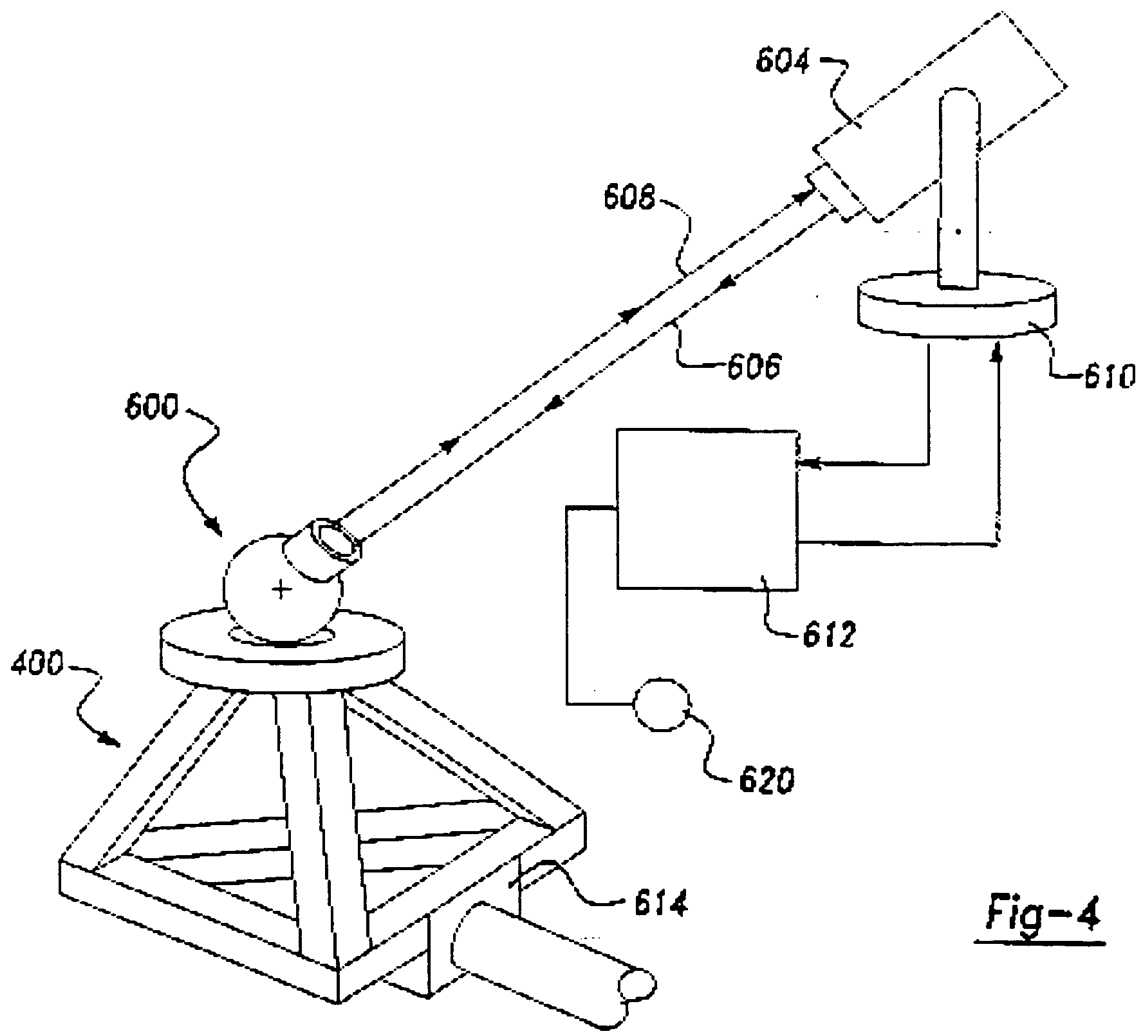

604
608
606
610
600
612
400
620
614

Fig-4